Wake Vortex Tracking Using a 35 GHz Pulsed Doppler Radar

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Introduction

- Aircraft spacings are an important factor in airport capacity
- Current spacings
  - Designed to provide safe separations regardless of conditions
  - Based largely on weight classifications
  - Considered conservative under most conditions

Current Separation Criteria

Following Aircraft	Leading Aircraft			
	Small	Large	B757	Heavy
Small	2.5	4	5	6
Large	2.5	2.5	4	5
Heavy	2.5	2.5	4	4

Small ≤ 41,000 lb Maximum Gross Takeoff Weight (MGW)
41,000 lb < Large ≤ 255,000 lb MGW
Heavy > 255,000 lb MGW
2.5 nm separation increased to 3 nm when runway occupancy time is > 50 sec

Remote Sensors for Vortex Separation System Development

- NASA, FAA, and international organizations seek to develop dynamic vortex separation systems
- Lidar has been utilized as a vortex sensor in clear air
- A 35 GHz radar has been developed as a complimentary low-visibility sensor

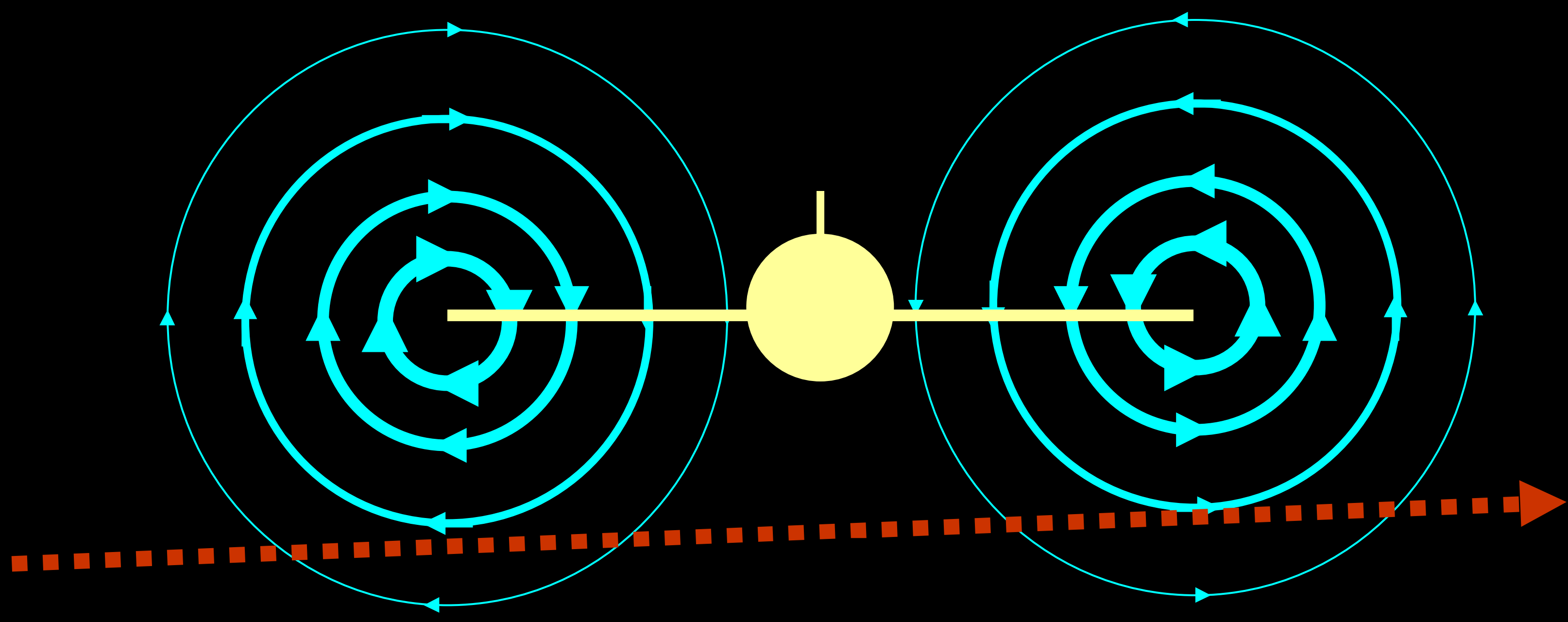
Radar System Description

- 35 GHz (ka band);
- Parabolic antenna, Cassegrain feed, 58 dBi gain;
- Antenna scan rate of 1 to 10 degrees/sec;
- Beam width of 0.185° in azimuth (10m cross range @ 3 km)
- 500 W peak power transmitter for developmental testing;
- 25 KHz and 12.5 KHz pulse repetition frequencies (PRF);
- Unambiguous ranges of 6 km and 12 km;
- 128 range cells and 512 Doppler frequencies;
- Optional, programmable pulse compression up to a 128-bit sequence;
- Pulse length from 5m to 640m

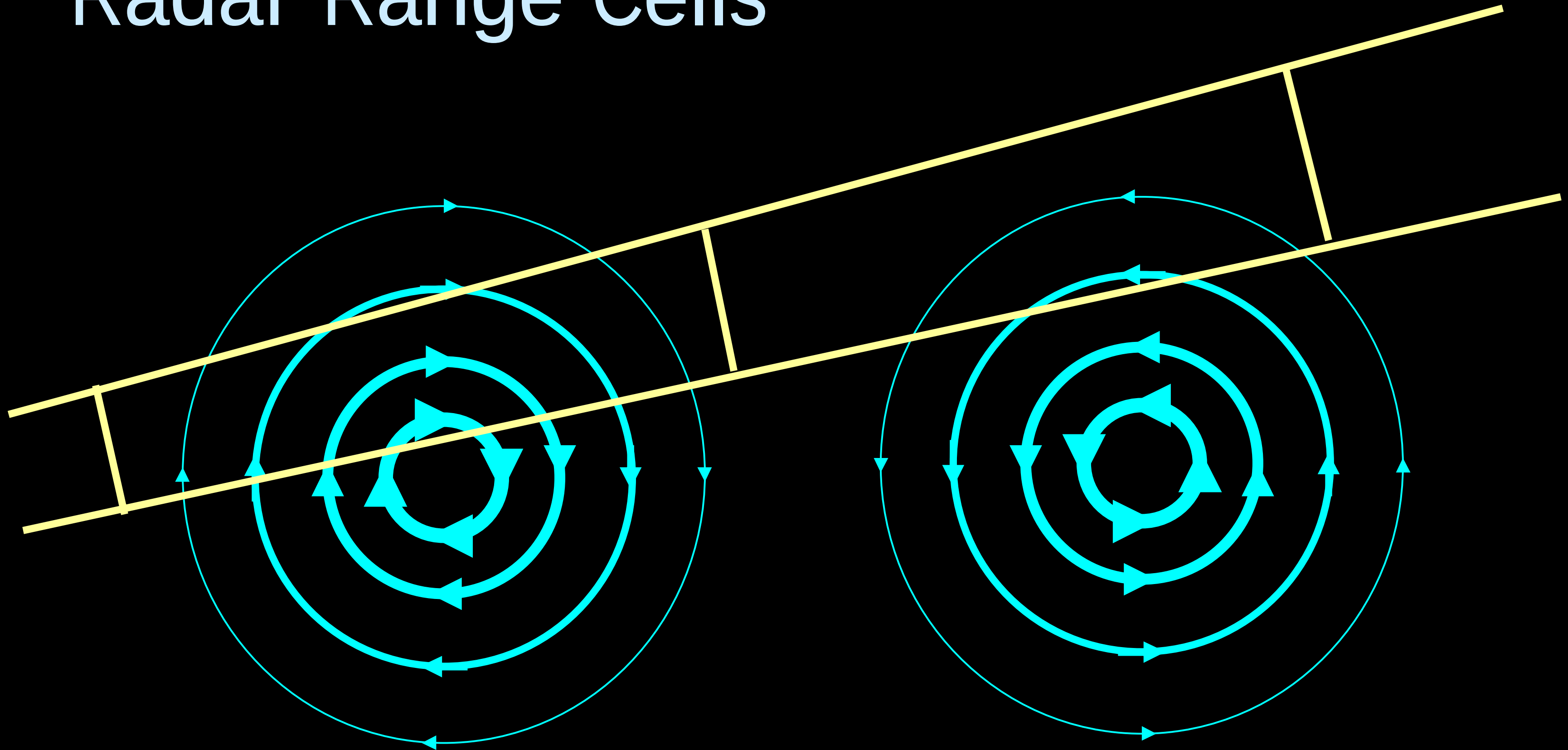
Detection and Resolution

- Detection requires sensing the velocity of hydrometeors in the vortices
- Spacial resolution is important to locate the cores and measure circulation
- Sensors respond to axial winds

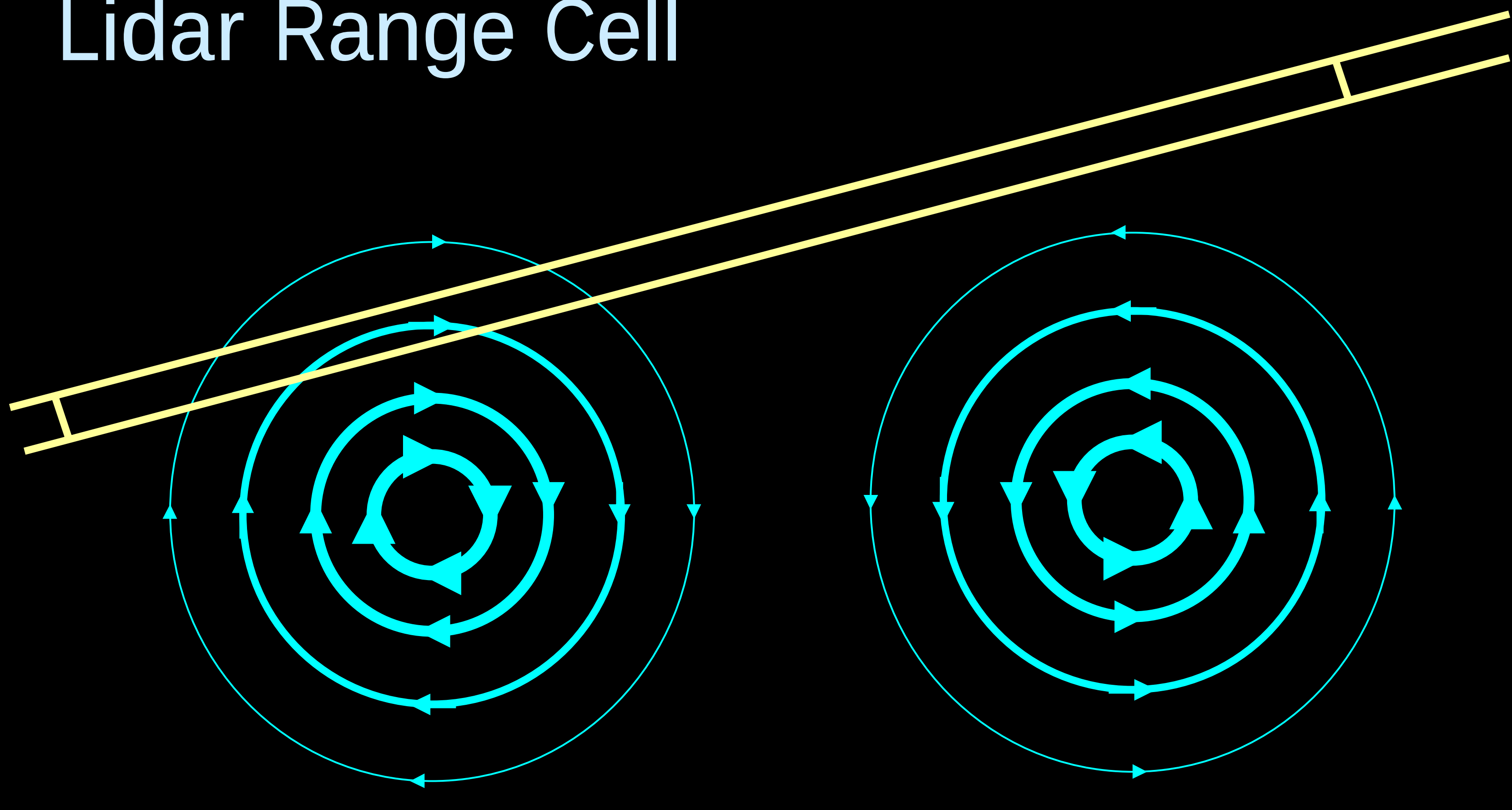
Vortex Rotation



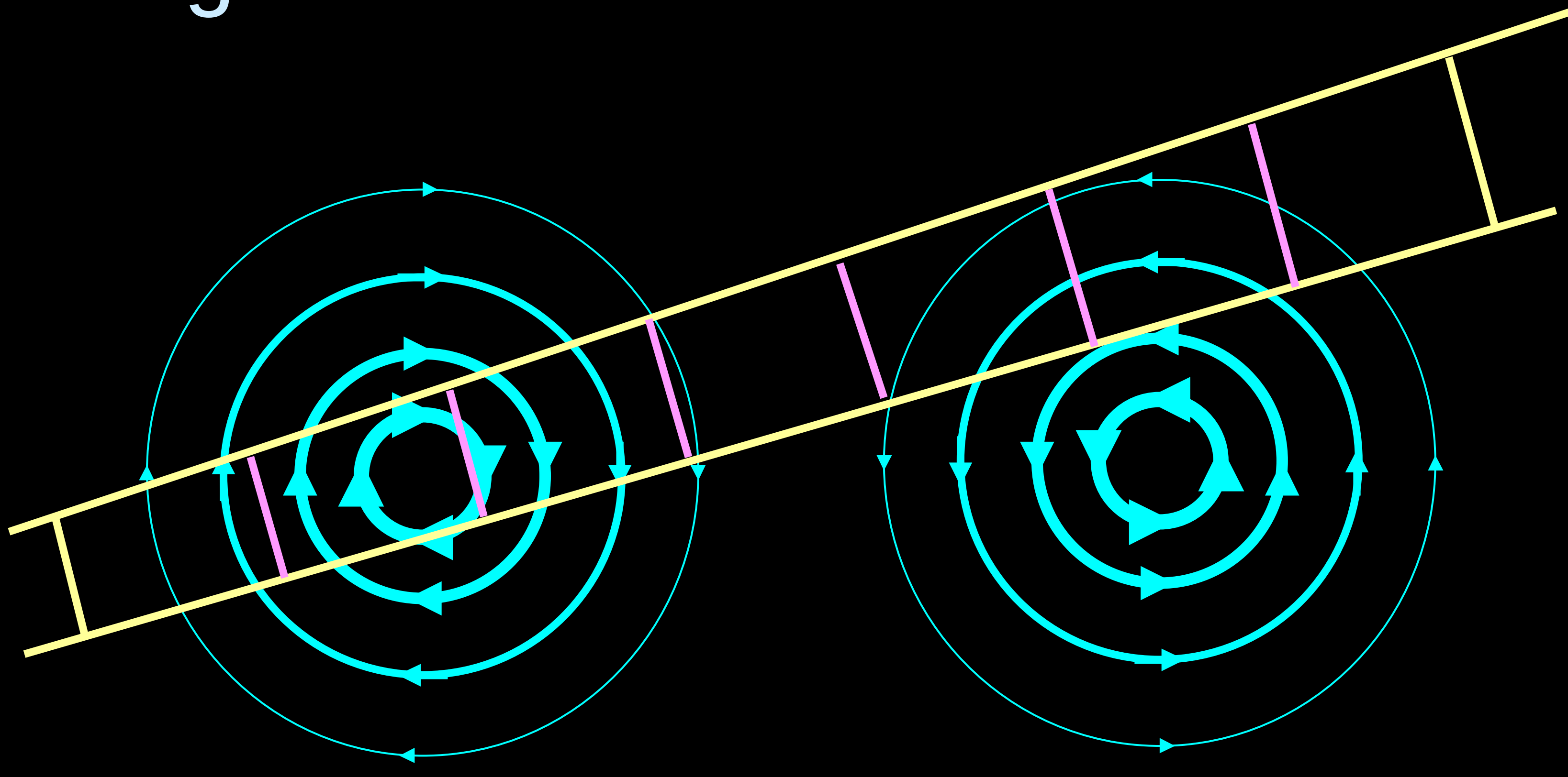
Radar Range Cells



Lidar Range Cell



Range Resolution



Radar Simulation Studies

- Purpose:
  - Update models
  - Implement Lidar-like processing
  - Study effects of pulse compression
  - Examine an example field site
- ADWRS - Airborne Doppler Weather Radar System model
- VR – Vortex Radar model includes pulse compression

Detection Studies

- Compare
  - Short pulses
  - Long pulses with Lidar-like processing
  - Pulse compression
- Examine spectra to identify best method
  - Detection
  - Core location

Table: Cases Run

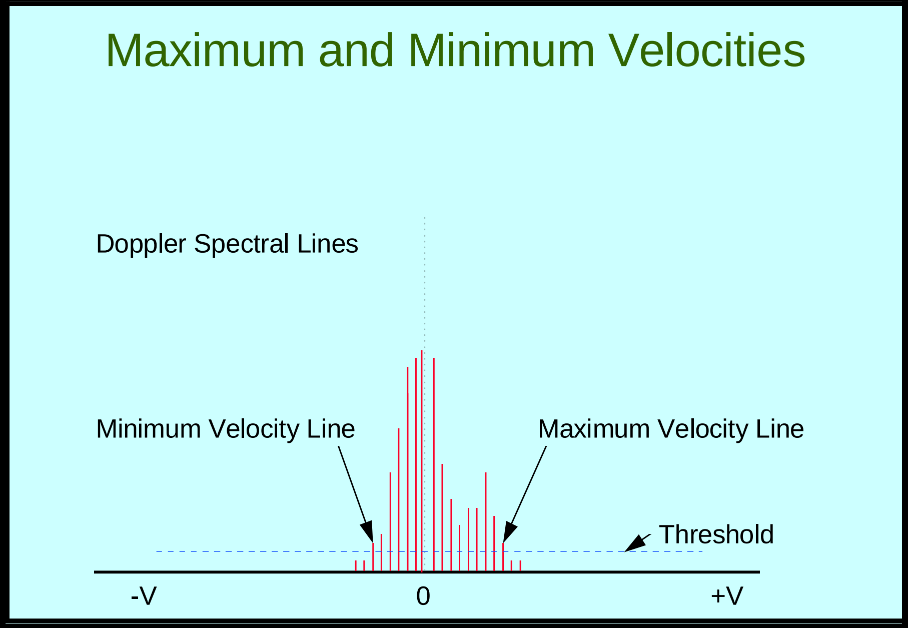
Range Res. (m)	Barker Code	Compressed		Uncompressed/Actual	
		Length (m)	Time (μs)	Length (m)	Time (μs)
4.9	4-Bit	4.9	0.0325	19.5	0.130
5.0	7-Bit	5.0	0.0330	34.7	0.231
5.0	13-Bit	5.0	0.0330	64.5	0.430
5.0	69-Bit [1]	5.0	0.0330	345	2.30
4.9	88-Bit [1]	4.9	0.0330	435	2.90
15	None	-	-	15.0	0.100
19.5	None	-	-	19.5	0.130
34.7	None	-	-	34.7	0.231
50	None	-	-	49.0	0.330
435	None	-	-	435	2.90

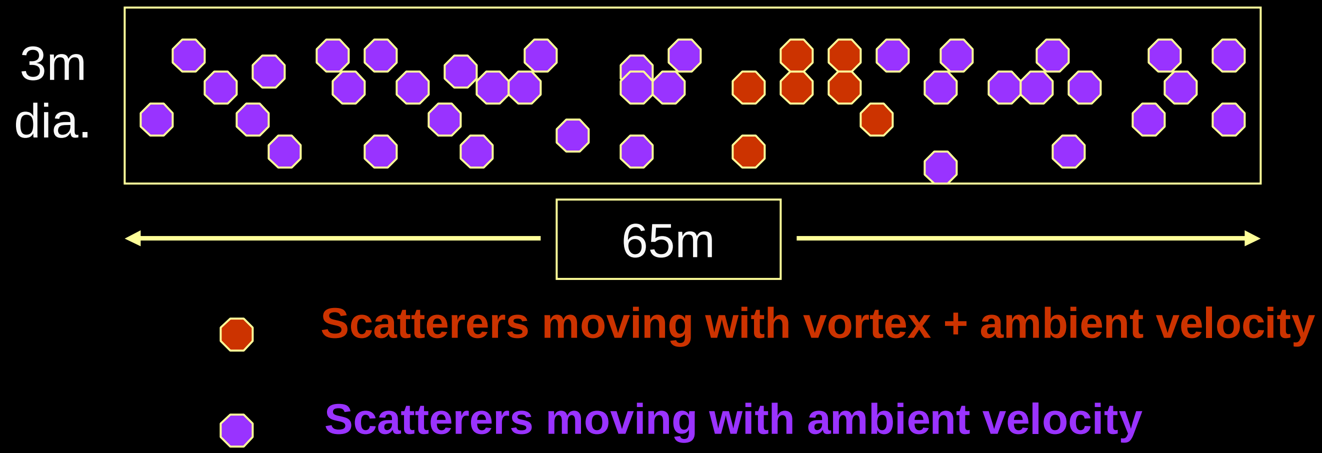
[1] Sequence of Barker codes

Lidar-like Processing

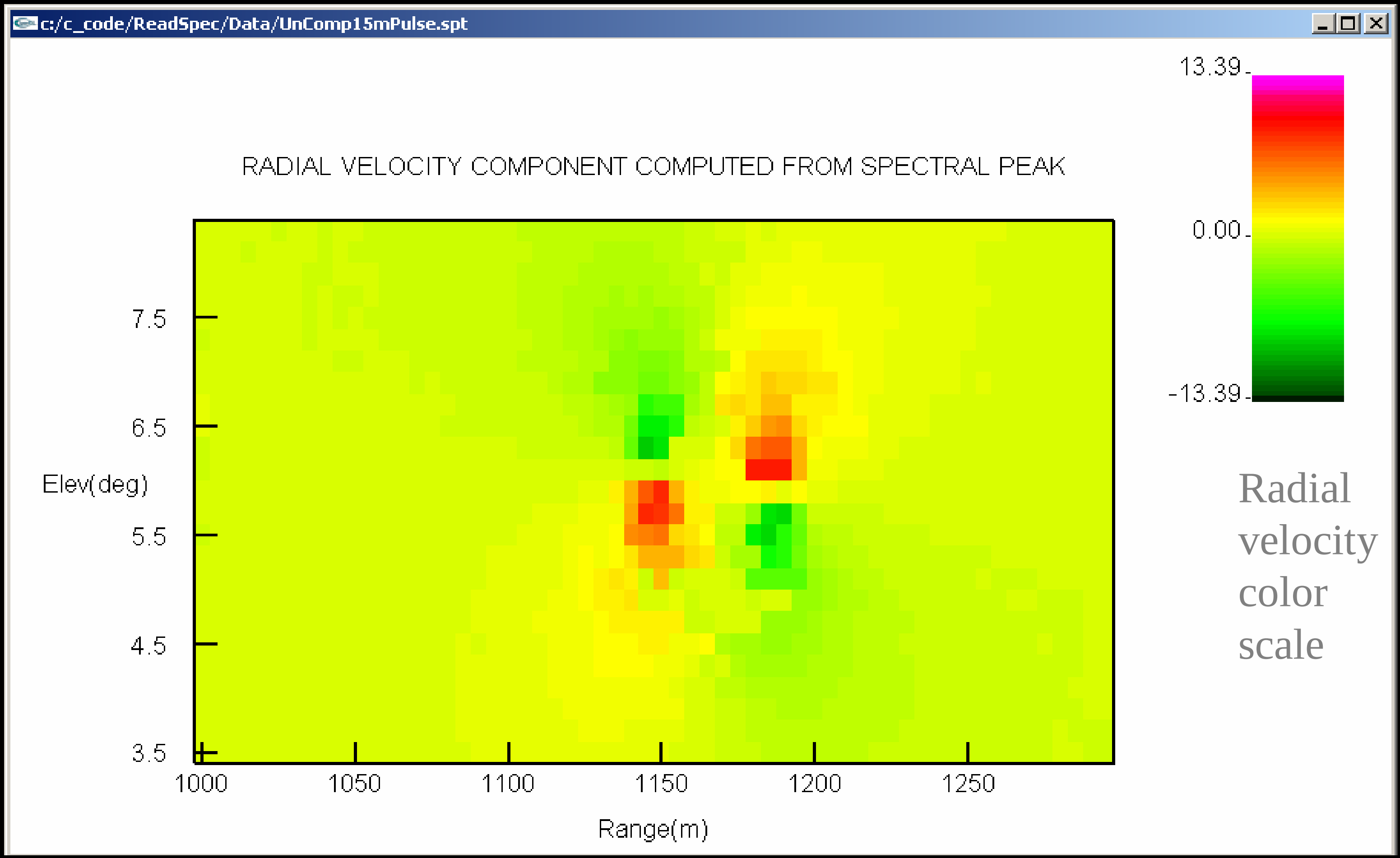
Velocity Spectra and

Resolution volume





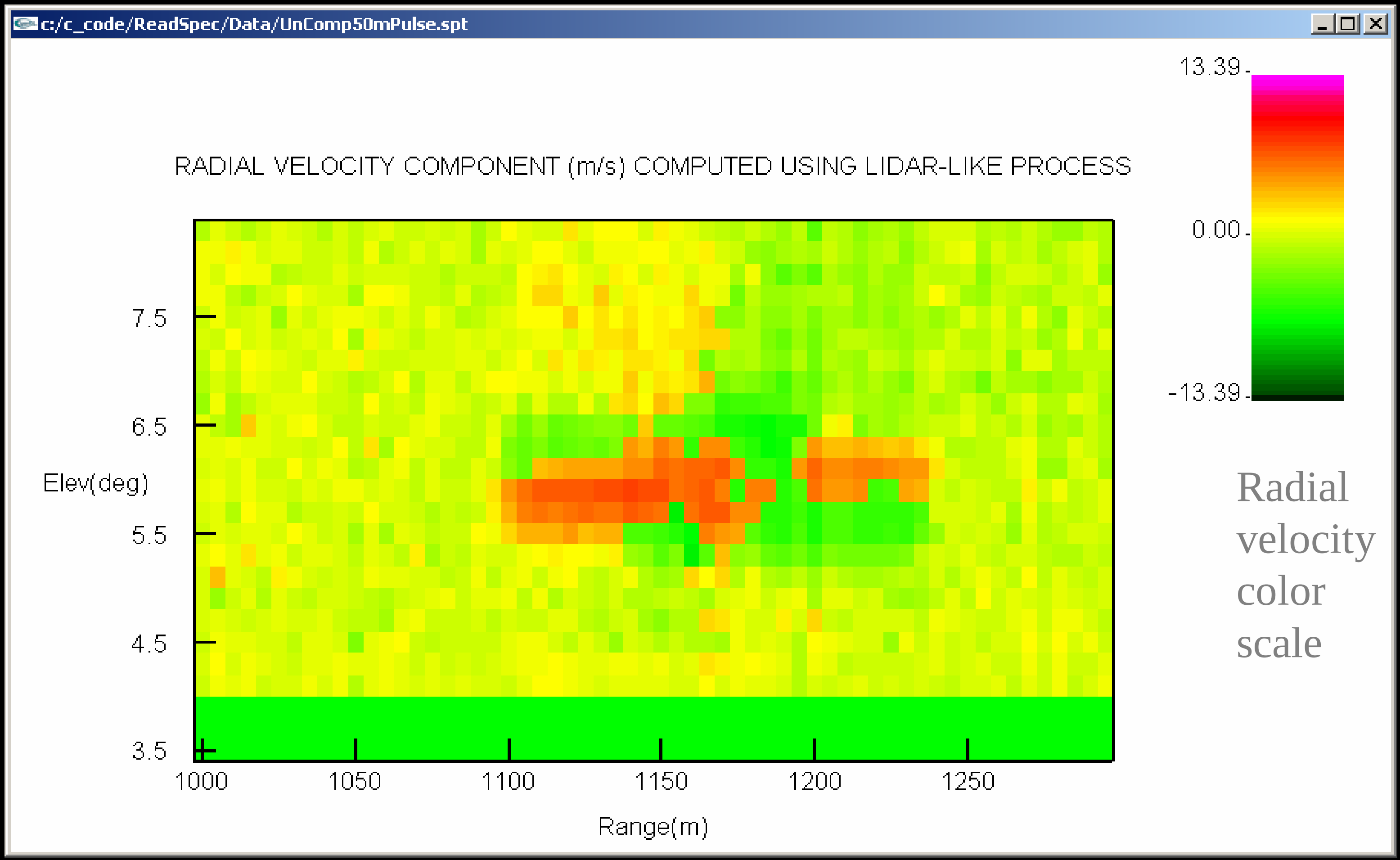
15m Uncompressed, Peak Detection



Radial velocity color scale

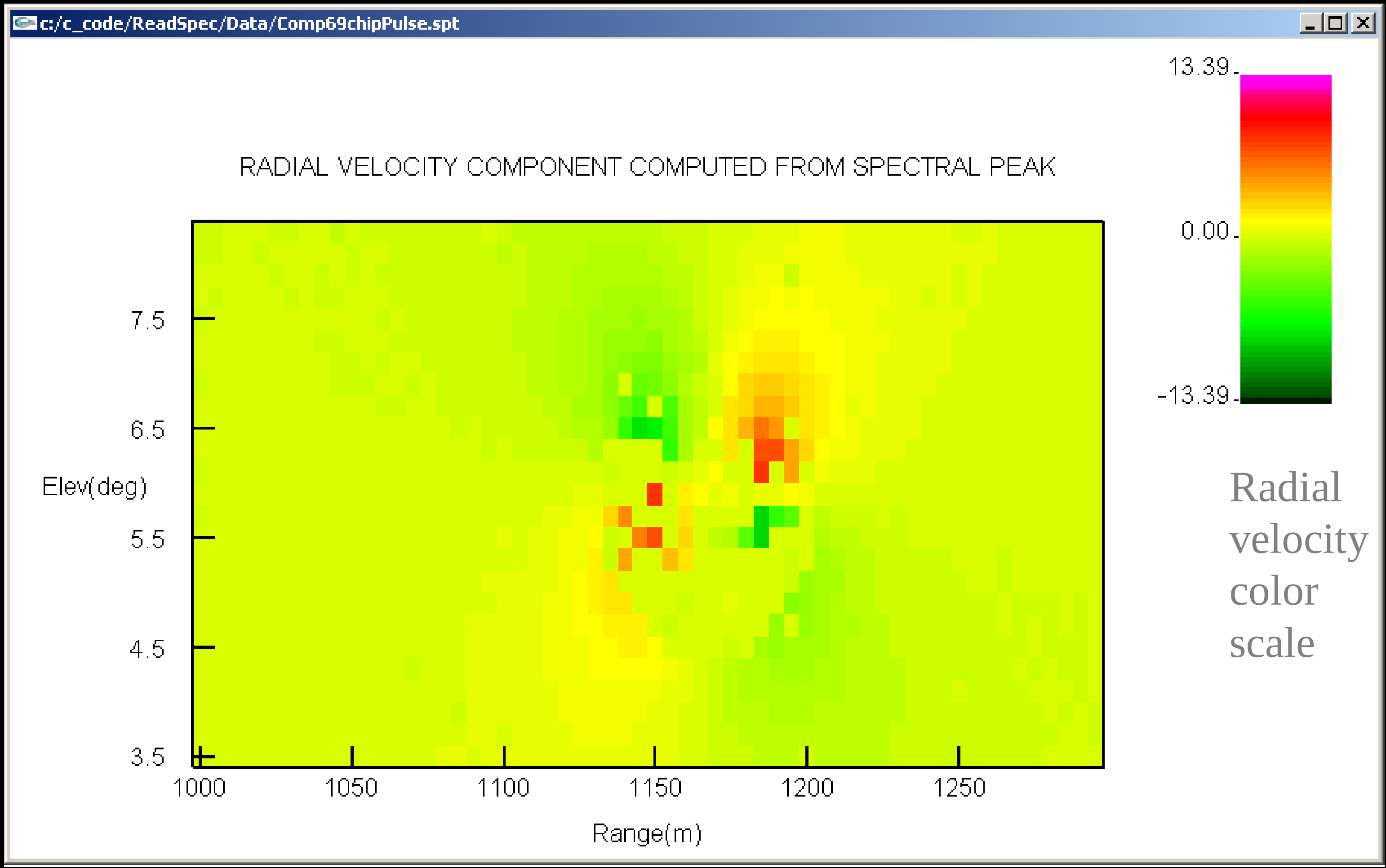
50m Uncompressed

Lidar–like processing



Radial velocity color scale

50m Uncompressed, Peak Detection



Radial velocity color scale

Pulse Compression

- Expected advantages
  - Higher average power for better detection range
  - Short range-resolution for good circulation estimates and core location
- Disadvantages
  - System complexity
  - Signal leakage between range cells

Pulse Compression vs. Short Pulse

Elevation Angle

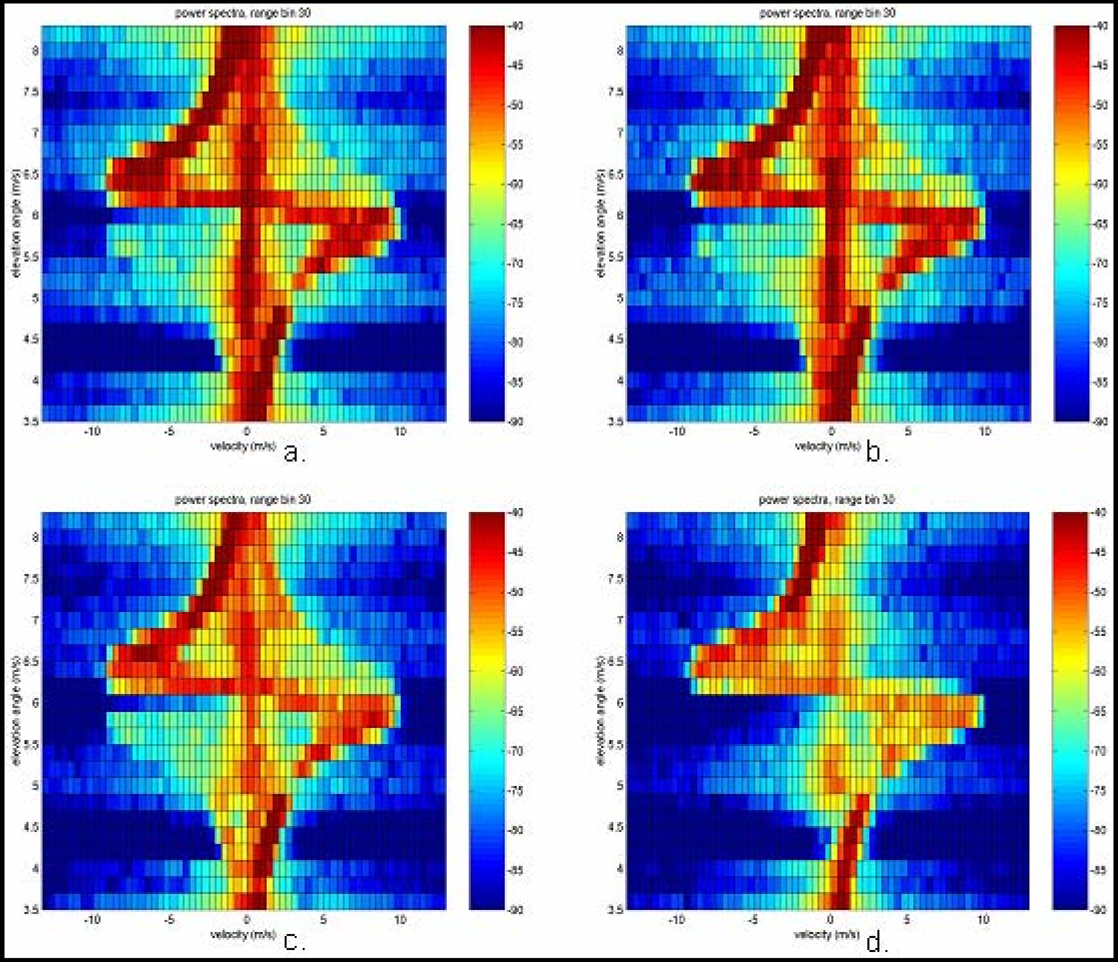
+ and - Velocity

88-bit Barker

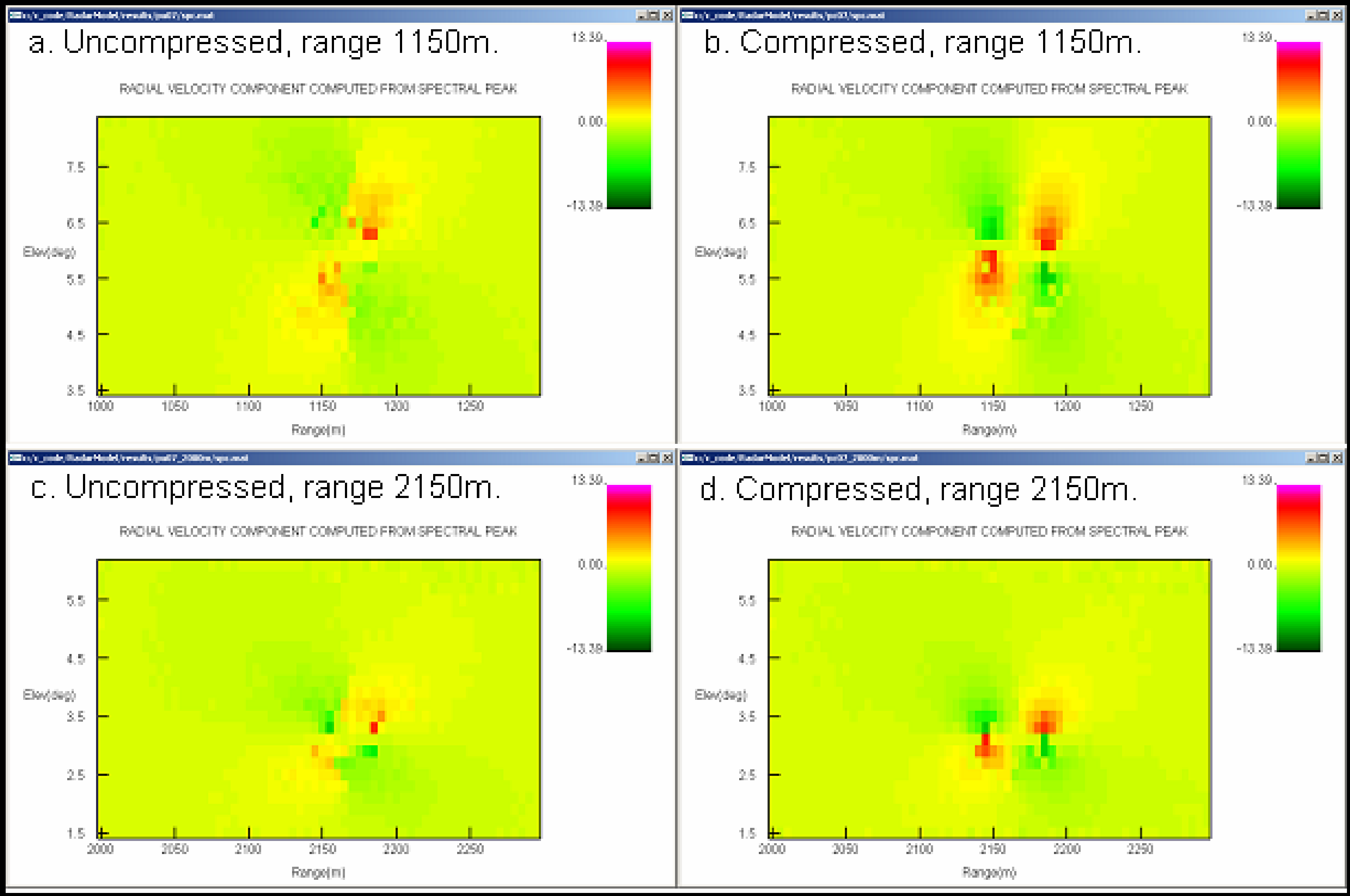
69-bit Barker

13-bit Barker

15m Uncomp.



Short Code: Uncompressed vs. 7-Bit Barker (35m)



Detection Summary

- Lidar-like processing is not productive
- Long pulse-compression codes allow significant leakage of ambient velocity
- Short uncompressed pulses provide good detection
- Short pulse-compression codes can extend range and sensitivity

Siting Factors – an Example

- San Francisco International (SFO)
- Limited open space
- Urban location
- Partially surrounded by water
- Suitable sites not on airport property
- Multiple site visits necessary

SFO Map

Microsoft® MapPoint®
South San Francisco
San Francisco Bay
Airport Blvd
S Airport Blvd
Harbor District San Mateo Cnty
82
CALIFORNIA
SFO [San Francisco Intern
California
380
Sneath Ln
San Bruno
35
SAN FRANCISCO
Potential Sites
82
280
Millbrae
101
SAN MATEO
101
San Mateo
Burlingame
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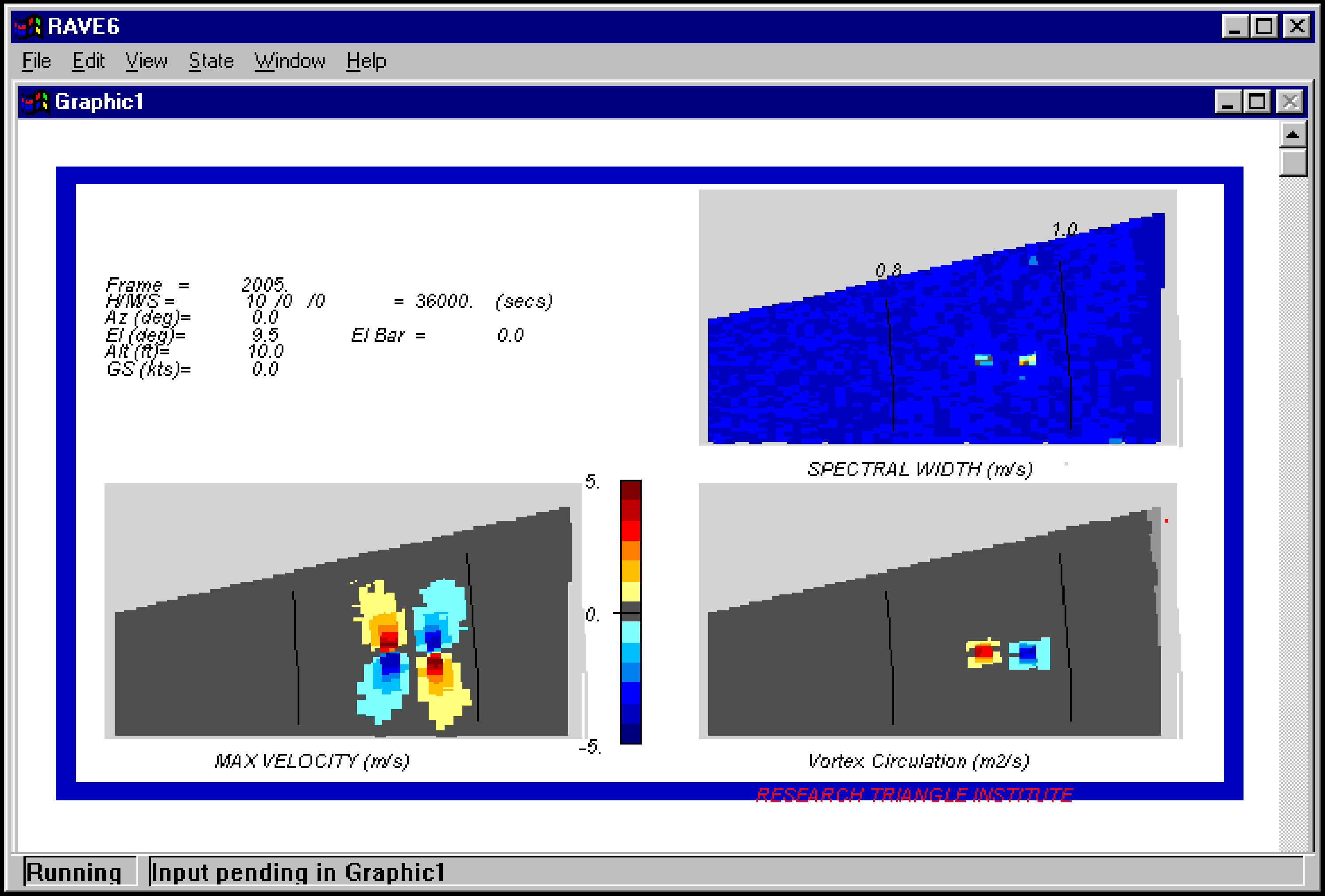
Site Particulars

- Runways 28L and 28R receive much arriving traffic
- Site perpendicular to approach
- Range 1600m, mostly over water
- Problems
  - Beam grazes ground/water
  - Small angular scan range
  - Degraded angular resolution

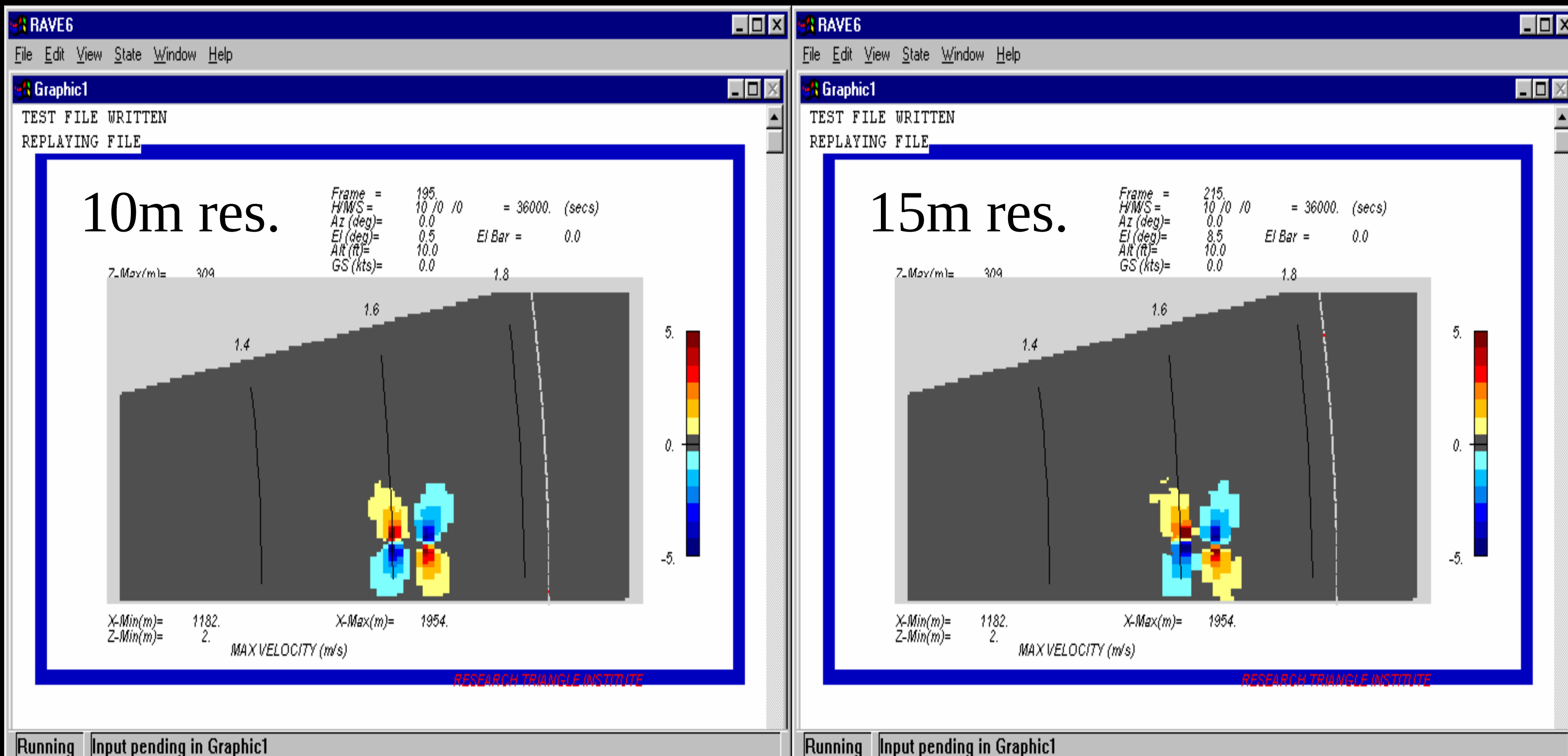
Table 2. Cases Run

Range (m)	Pulse Width (ns)	Range Resolution (m)	Reflectivity (dBZ)
900	33	5	15
900	66	10	15
900	99	15	15
1600	66	10	15
1600	99	15	15
900	66	10	-13
1600	66	10	-13

Baseline: 900m, 66ns pulse (10m), 15 dBZ reflectivity

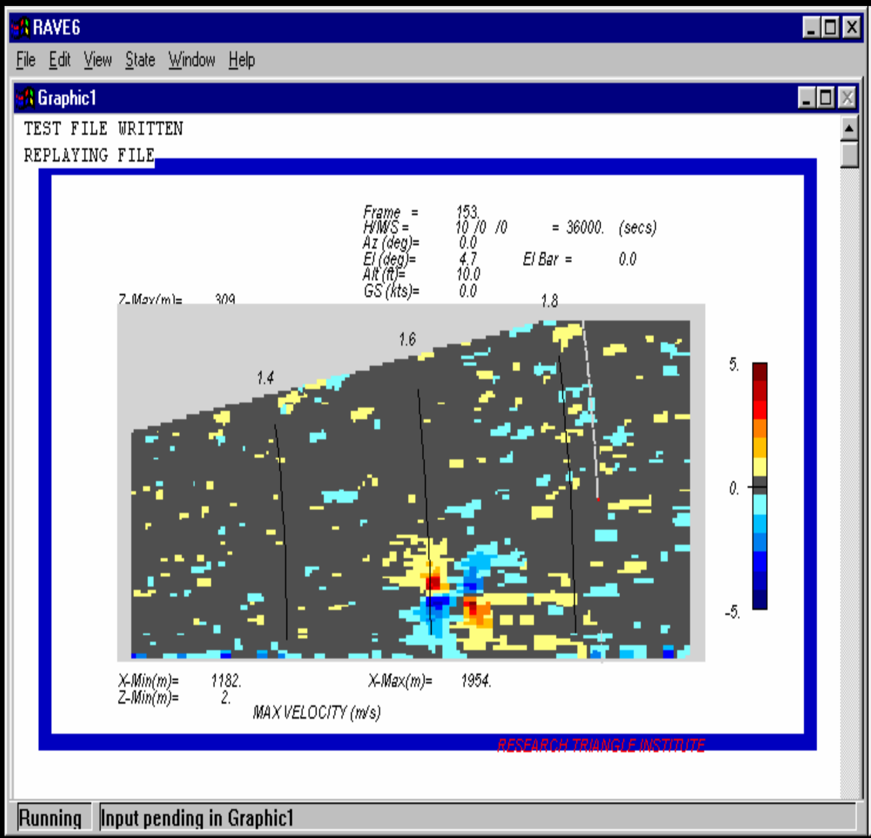


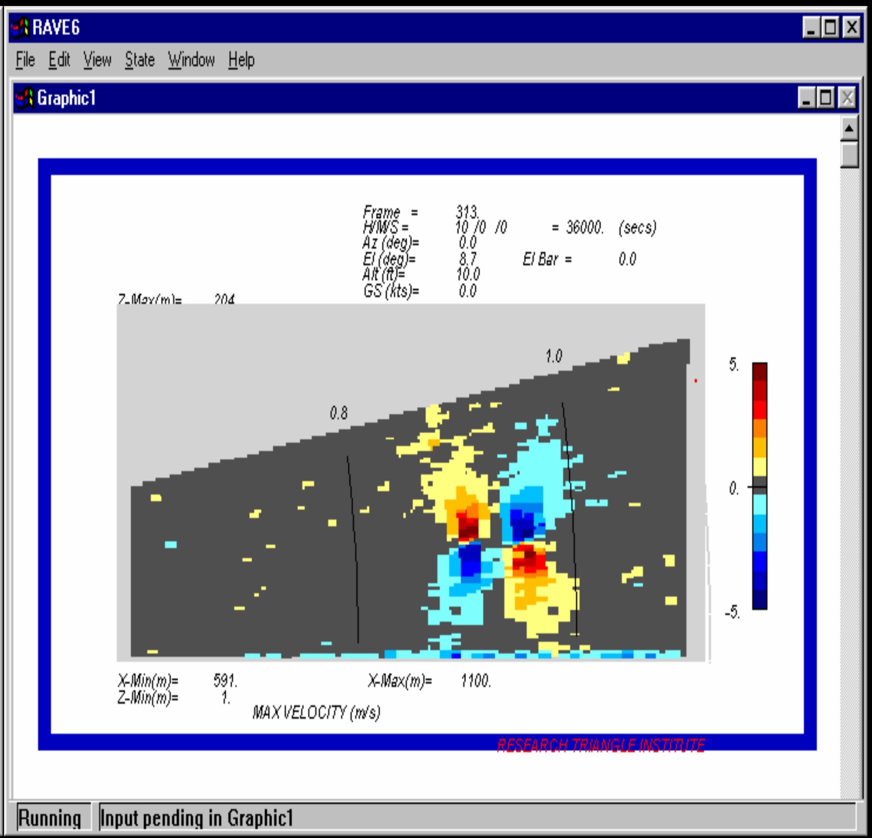
1600m range, 10m vs. 15m range resolution, 15 dBZ reflectivity



Sharper range resolution provides better core location and circulation estimates.

Marginal Conditions: 1600m vs. 900m range





1600m

900m

-13 dBZ reflectivity, 66ns pulse (10m)

Conclusions

- 35 GHz radar has the potential to function as a low-visibility sensor for wake vortices
- Simulations predict good detection in medium to heavy fog to 2000m
- Peak detection and good range resolution are required
- Short pulse-compression codes can be used to extend range and sensitivity